

# Impact of Climate Change on Meteorology and Regional Air Quality in California

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# Air Pollution and Health

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- Increased mortality and morbidity associated with high concentrations of atmospheric pollutants
  - Airborne particles (see for example Pope et al., 2000)
  - Ozone (see for example Levy et al., 2005)

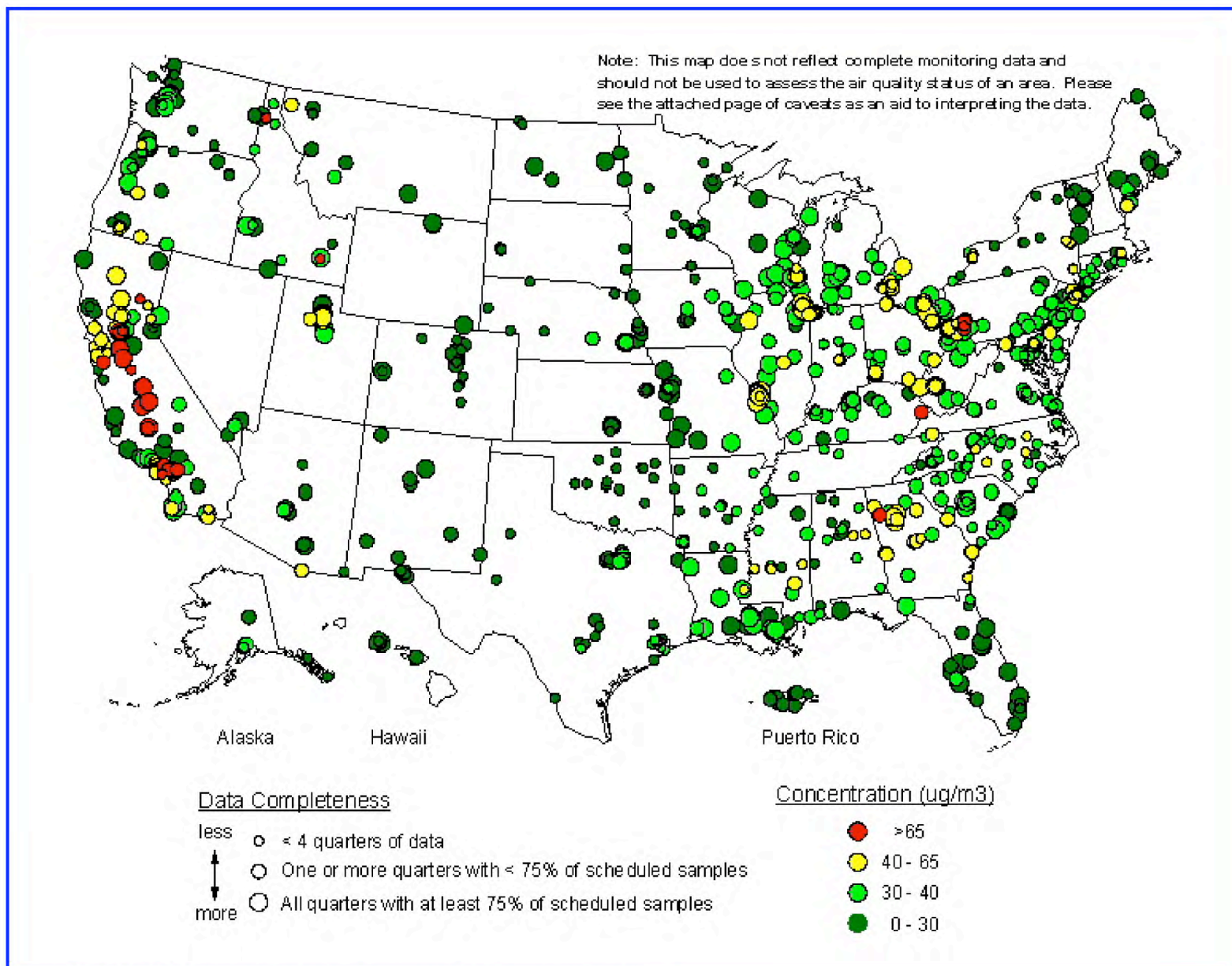


# Air Pollution in California

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- California has two of the most severely polluted air basins in the United States
  - South Coast Air Basin
  - San Joaquin Valley





**Figure 2. 1999 98<sup>th</sup> percentile 24-hour average PM<sub>2.5</sub> concentrations.**

Source: U.S. EPA AIRS data base, July 12, 2000.

# How Will Climate Change Affect Air Pollution in California?

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- Most air pollution events are driven by stagnant atmospheric conditions
  - High Pressure systems stall over California
- The frequency of stagnation events will likely change with climate
- The characteristics of the typical stagnation event will likely change with climate
  - Temperature, humidity, mixing depth, wind speed, etc





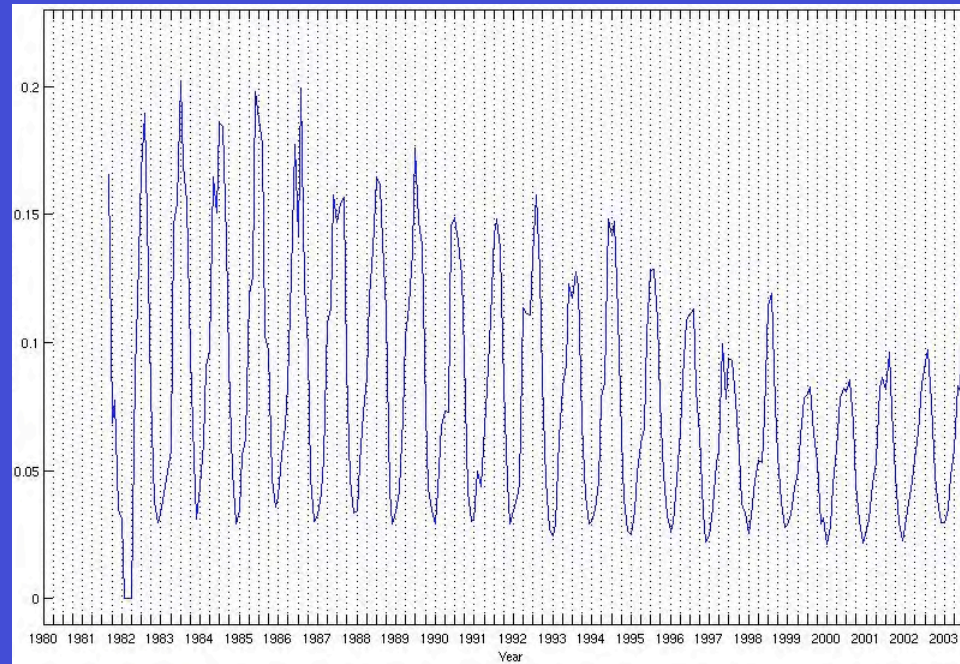
# Climate change projections of air quality over California

## Approach

Develop statistical relationships between air quality measurements and model data

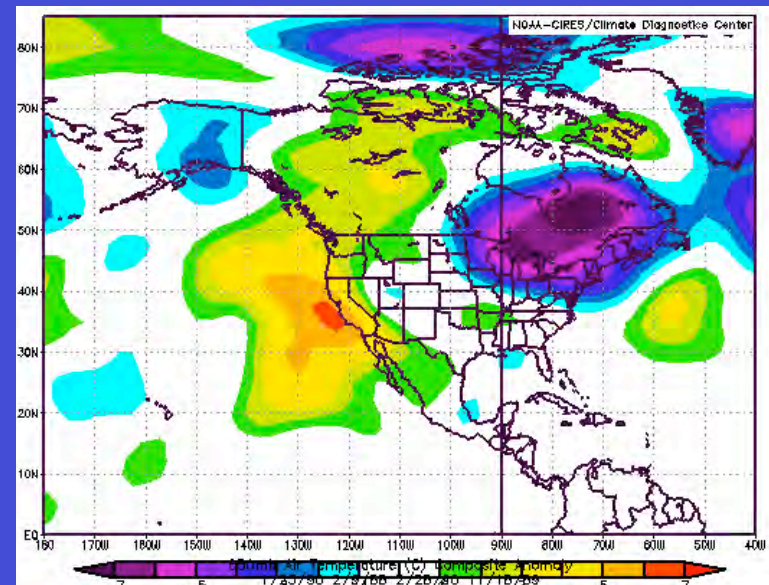
Select sites in California with longest (time) and densest (sampling) records; remove trend from time series (if needed)

Fontana ozone (ppm) 1980-2002



Choose model similar to climate model which has simulations using observed conditions -- NCEP/NCAR reanalysis<sup>1</sup>

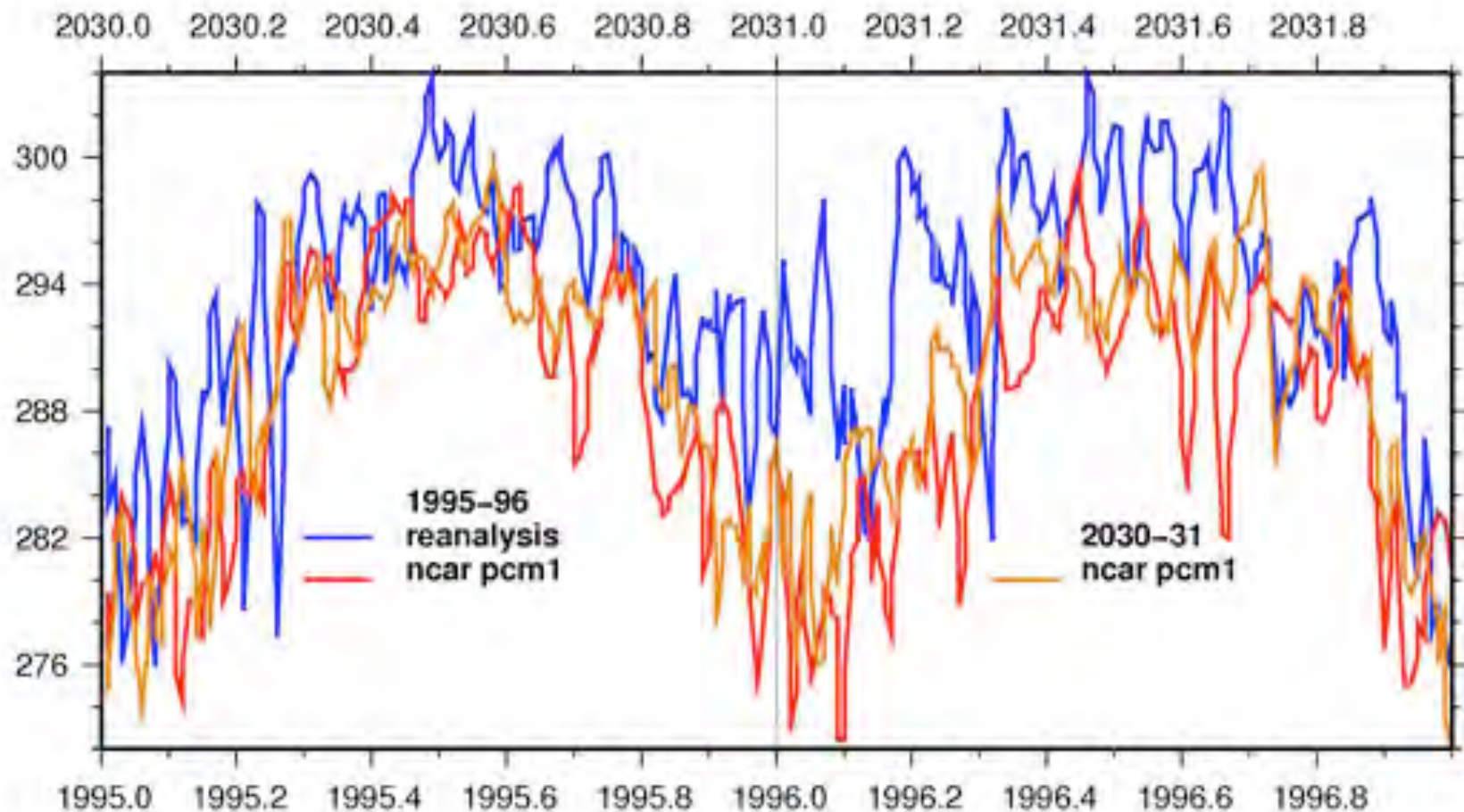
850mb temperature anomalies on days when the fine particulate matter over Bakersfield was high



## Climate change projections of air quality over California

VISALIA

may/jun/jul/aug/sep/oct daily 850mb temperature



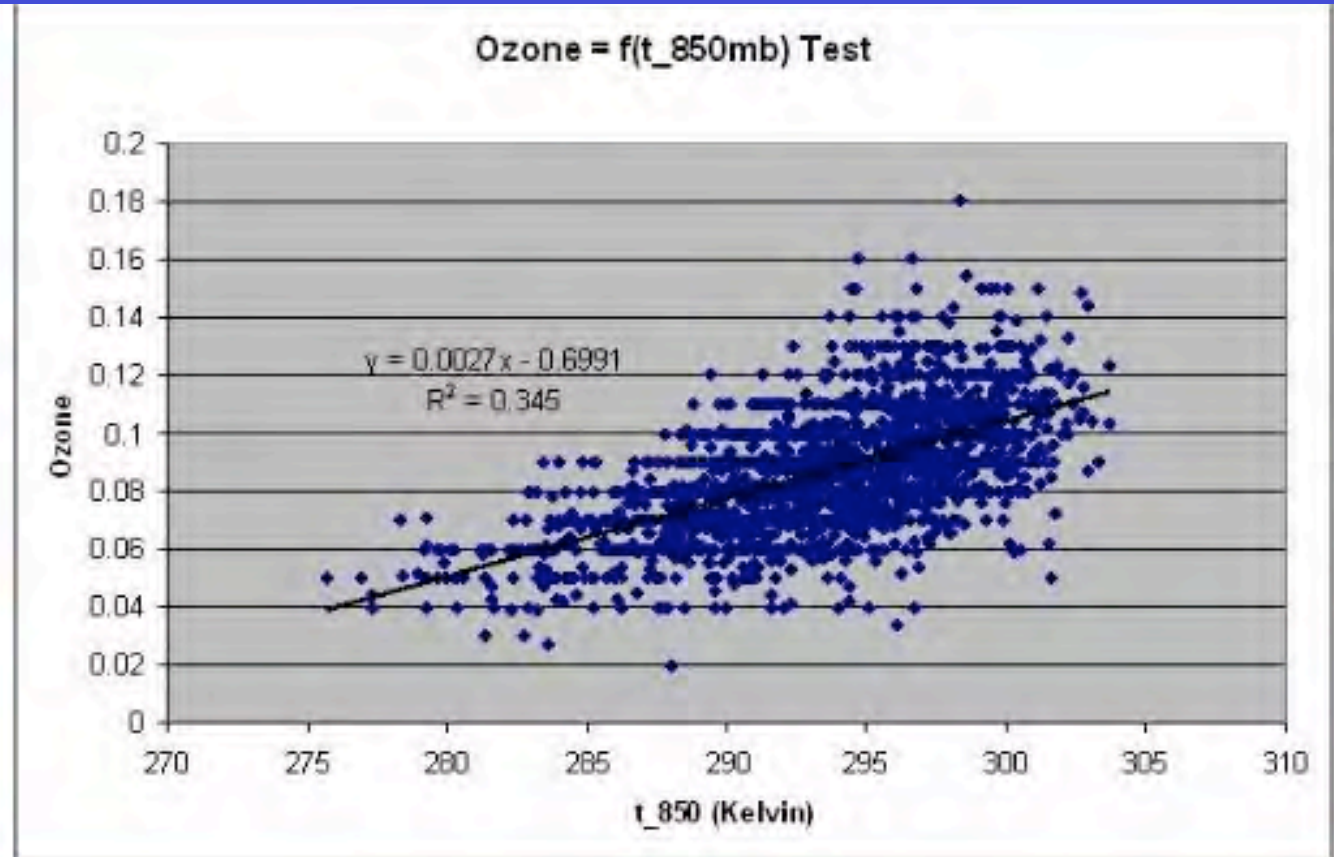
Daily temperature at 850mb for 2 years in the historical period -- reanalysis (observed) and NCAR PCM1 (model; only gg forcing) -- and for 2 years in the climate change period (NCAR PCM1 SRES B1)



# Climate change projections of air quality over California

## Ozone

Linear (least squares) regression between the JJA daily ozone and NCEP Reanalysis 850mb temperature over Visalia

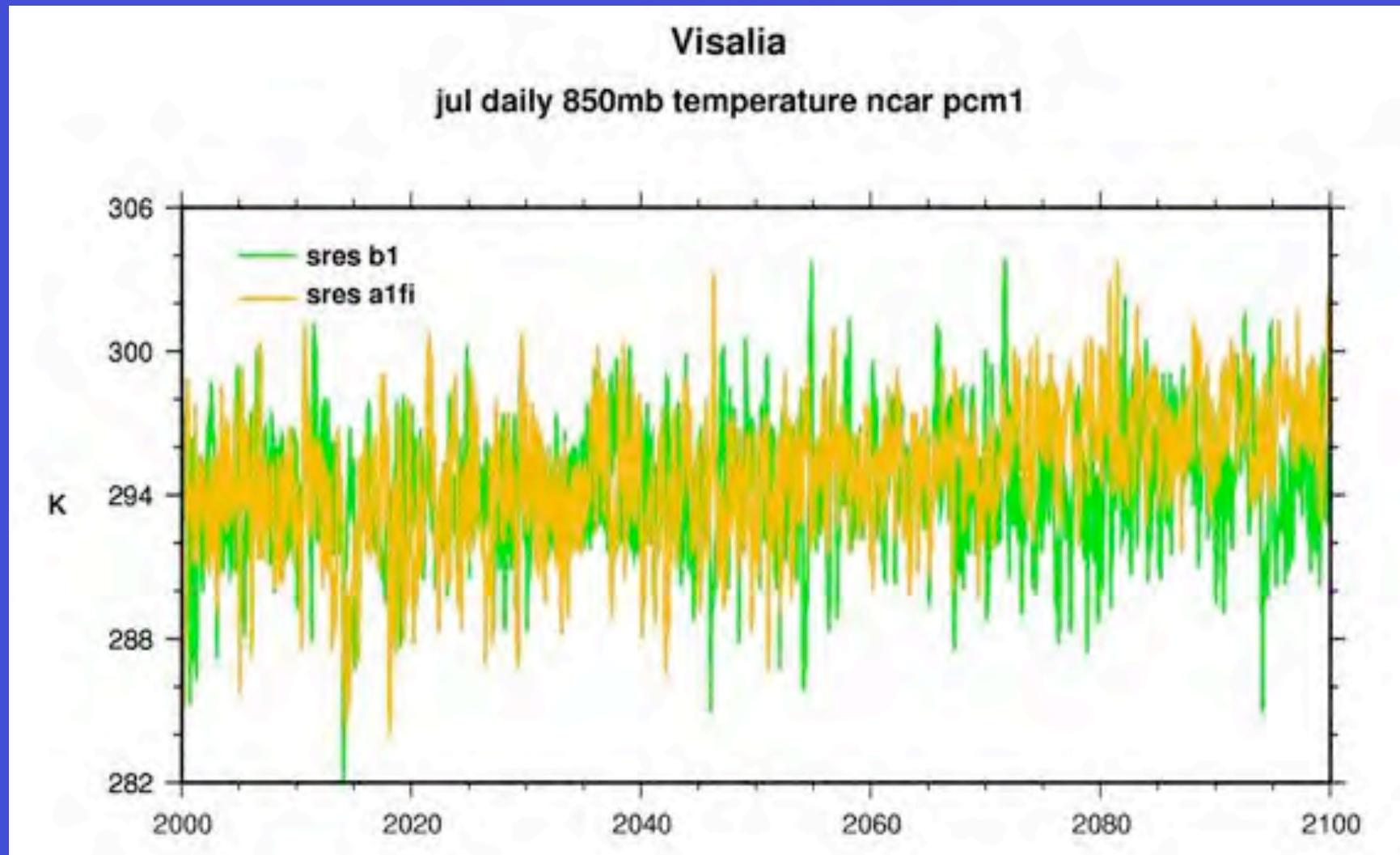


## Riverside multiple regression summary for May through October

Coefficients									
	constant	T850(d0)	T850(d-1)	T925(d0)	T925(d-1)	uv850	uv925	uv1000	n (sample size)
1980-1986	-2.0006	0.006122	0.000122	0.008048	-0.00698	-0.00418	-0.00228	0.00638	733
1988-1994	-1.2766	0.006962	-0.00272	0.003416	-2.91E-03	-1.80E-03	-0.00346	0.00537	732
1996-2002	-0.99864	0.003472	-0.00102	0.00387	-0.00263	7.45E-05	-0.00076	0.00127	732
r <sup>2</sup> 's									
1980-1986	0.57								
1988-1994	0.49								
1996-2002	0.56								

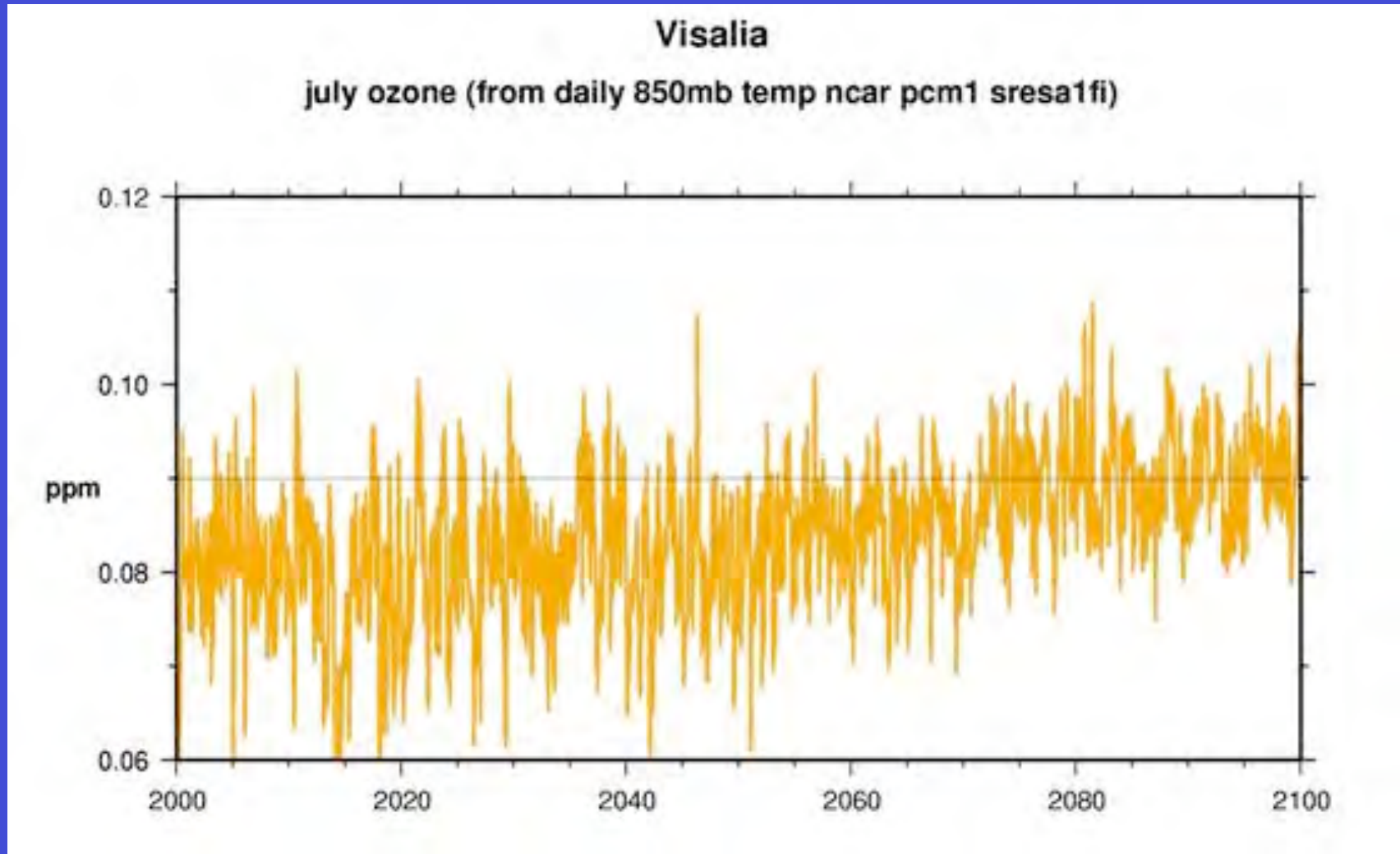


## Climate change projections of air quality over California



July daily temperature at 850mb for 2000-2099 from NCAR PCM1 SRES B1 and SRES A1fi

## Climate change projections of air quality over California



July daily ozone using temperature at 850mb for 2000-2099 from NCAR PCM1 SRES A1fi as predictor

# Characteristics of Stagnation Events

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- Climate change will cause multiple variables to shift simultaneously
  - Temperature, humidity, mixing depth, wind speed, etc.
- As a first step, we need to understand the effect that each variable has on the air pollution system



# Air Pollution and Temperature

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- Direct effect of temperature
  - gas phase reaction rate constants
  - gas-to-particle partitioning
- Reaction rate constants usually take the form of an Arrhenius equation:

$$k = A \times \exp(-E/RT)$$

- Hotter temperatures usually lead to increased reaction rates





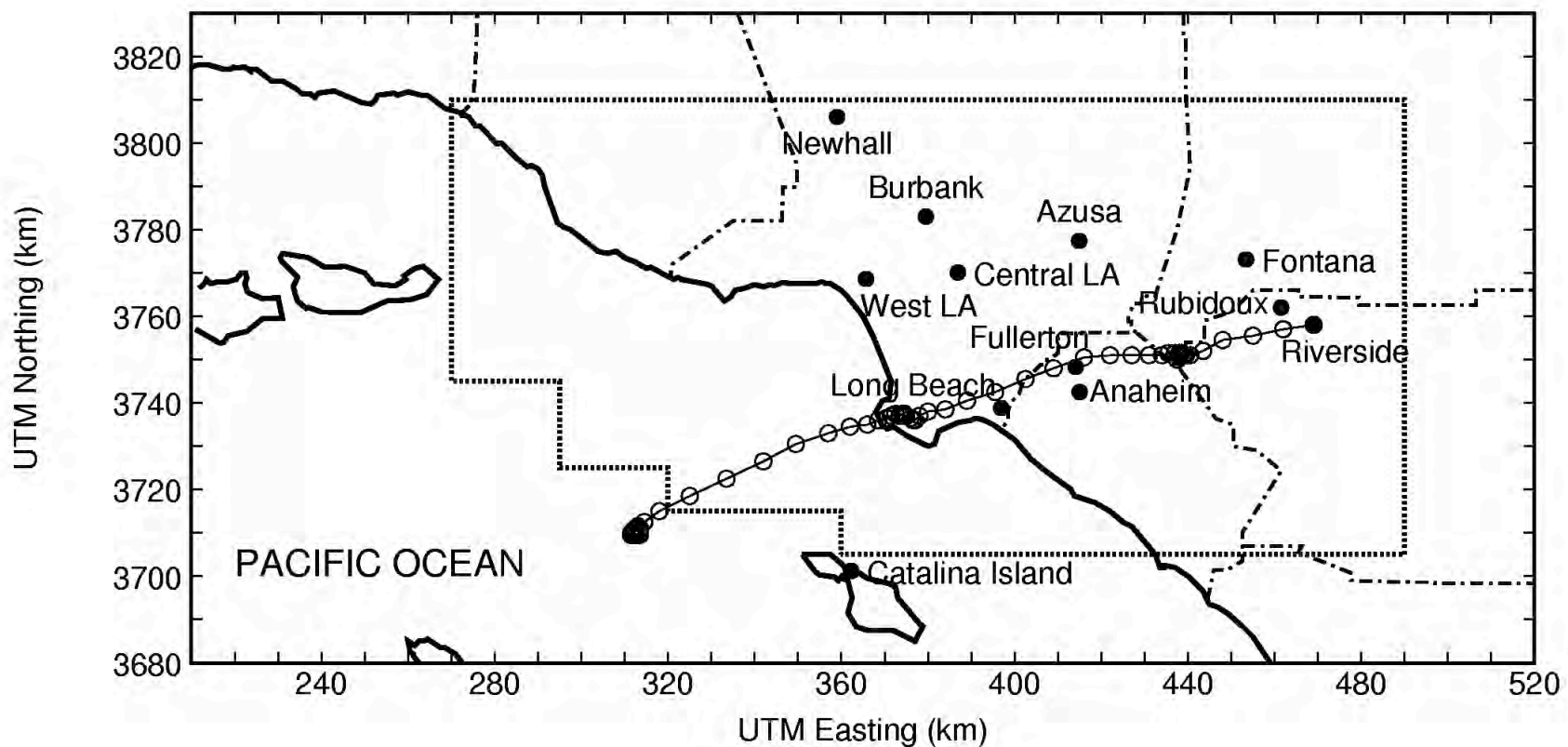
# Inorganic Partitioning

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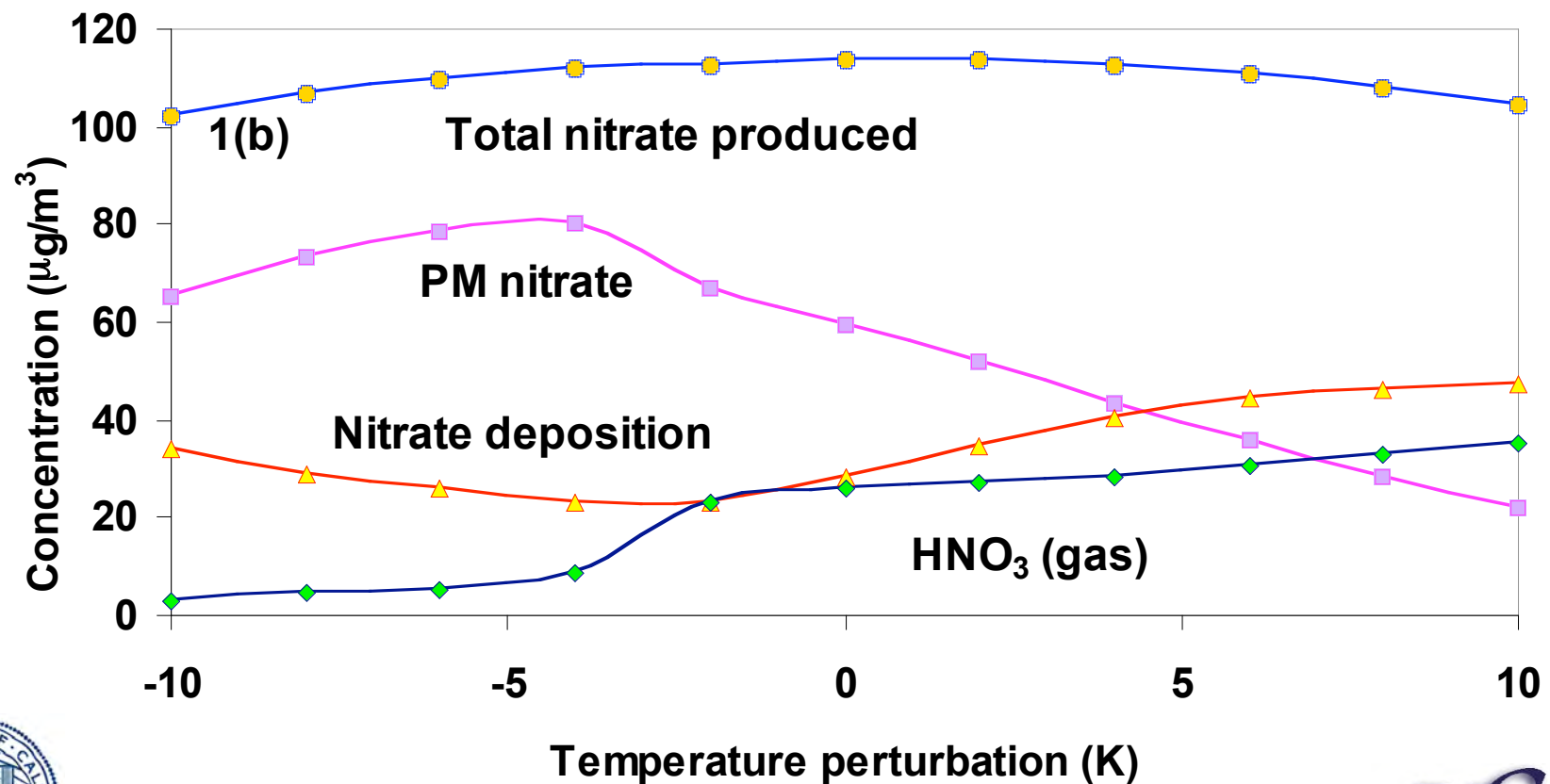
- Semi-volatile inorganics also try to reach equilibrium
  - $H_{Ai} = A_i / G_i$
- $H_A$  is a function of temperature
  - $H_{A,T2} = H_{A,i,T1} \times \exp[\Delta H_A / R(1/T_1 - 1/T_2)]$
- As  $T_2$  increases,  $H_A$  decreases
  - ▶ more secondary inorganic in gas phase



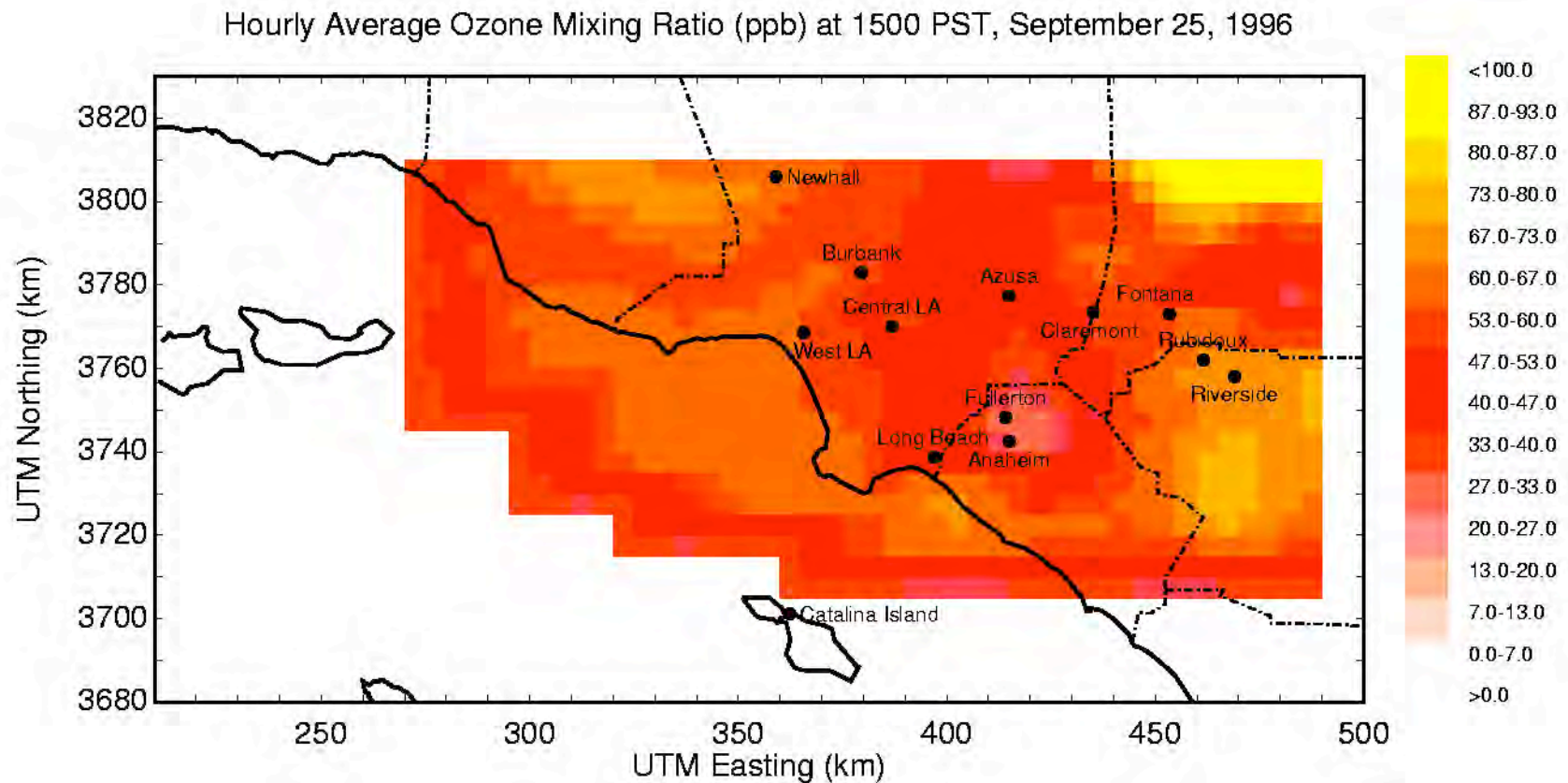
# Trajectory Path Arriving in Riverside September 25, 1996



# Nitrate Response to Temperature



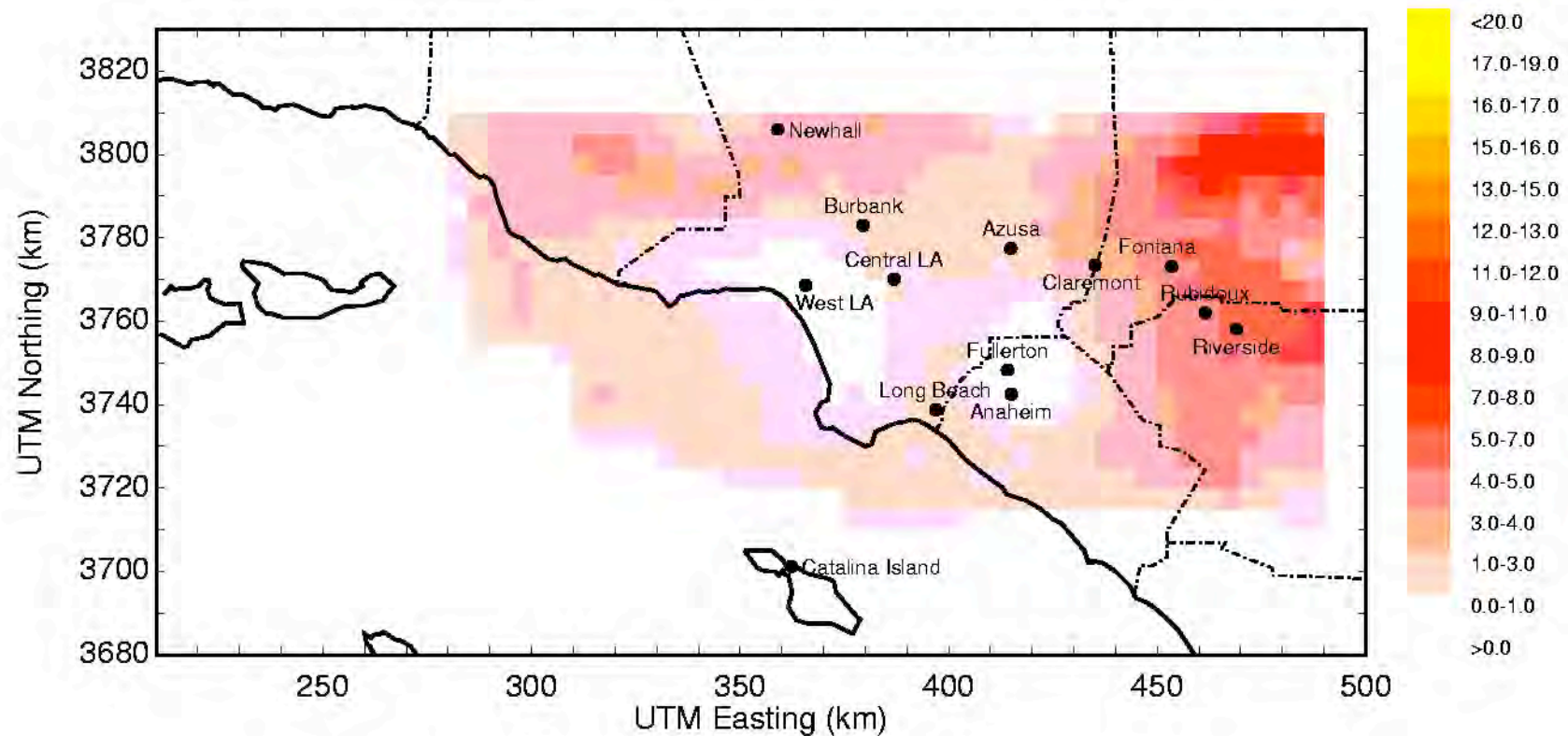
# Basecase Ozone Concentrations



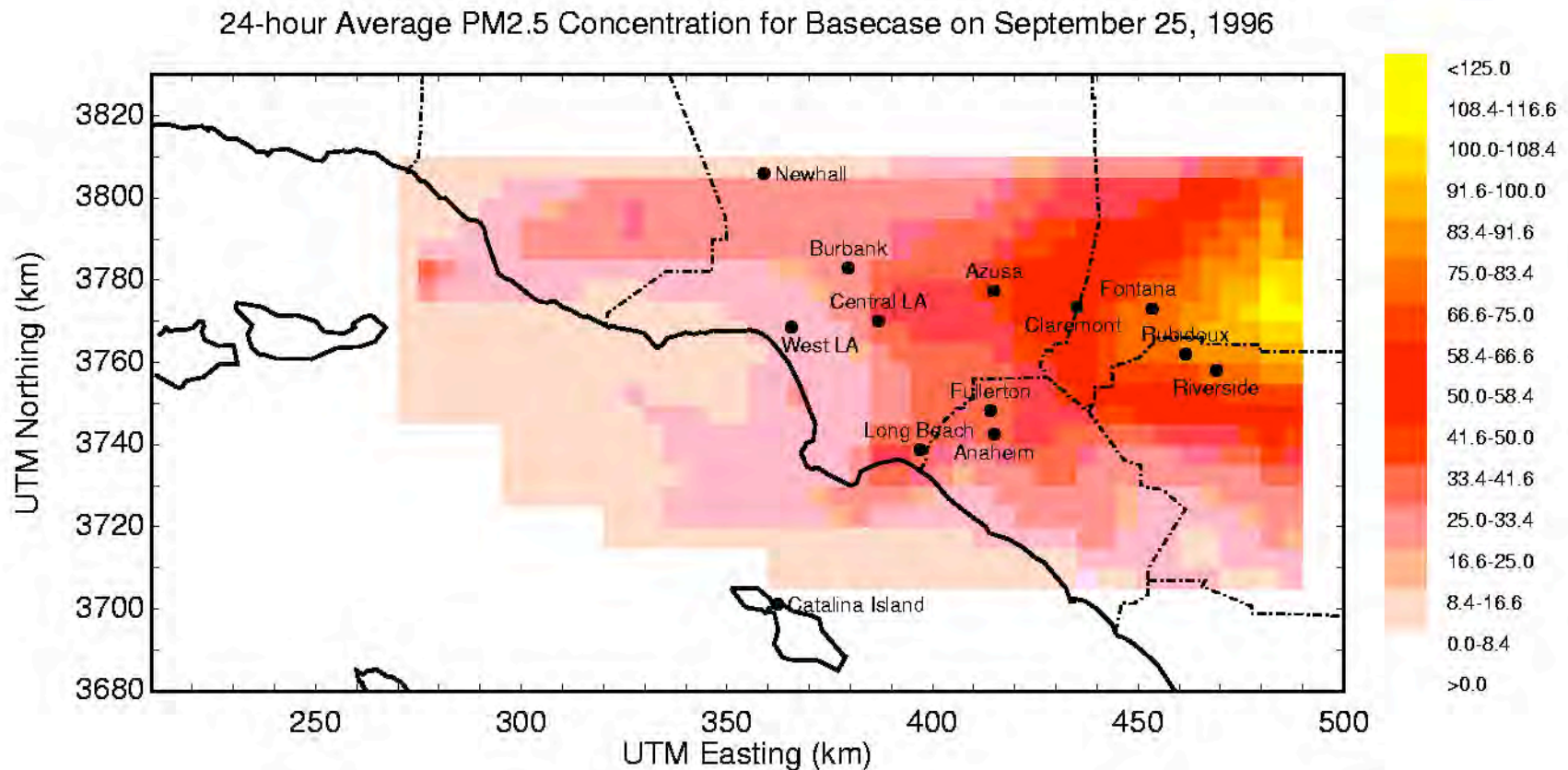


# $\Delta O_3$ Response to +2K

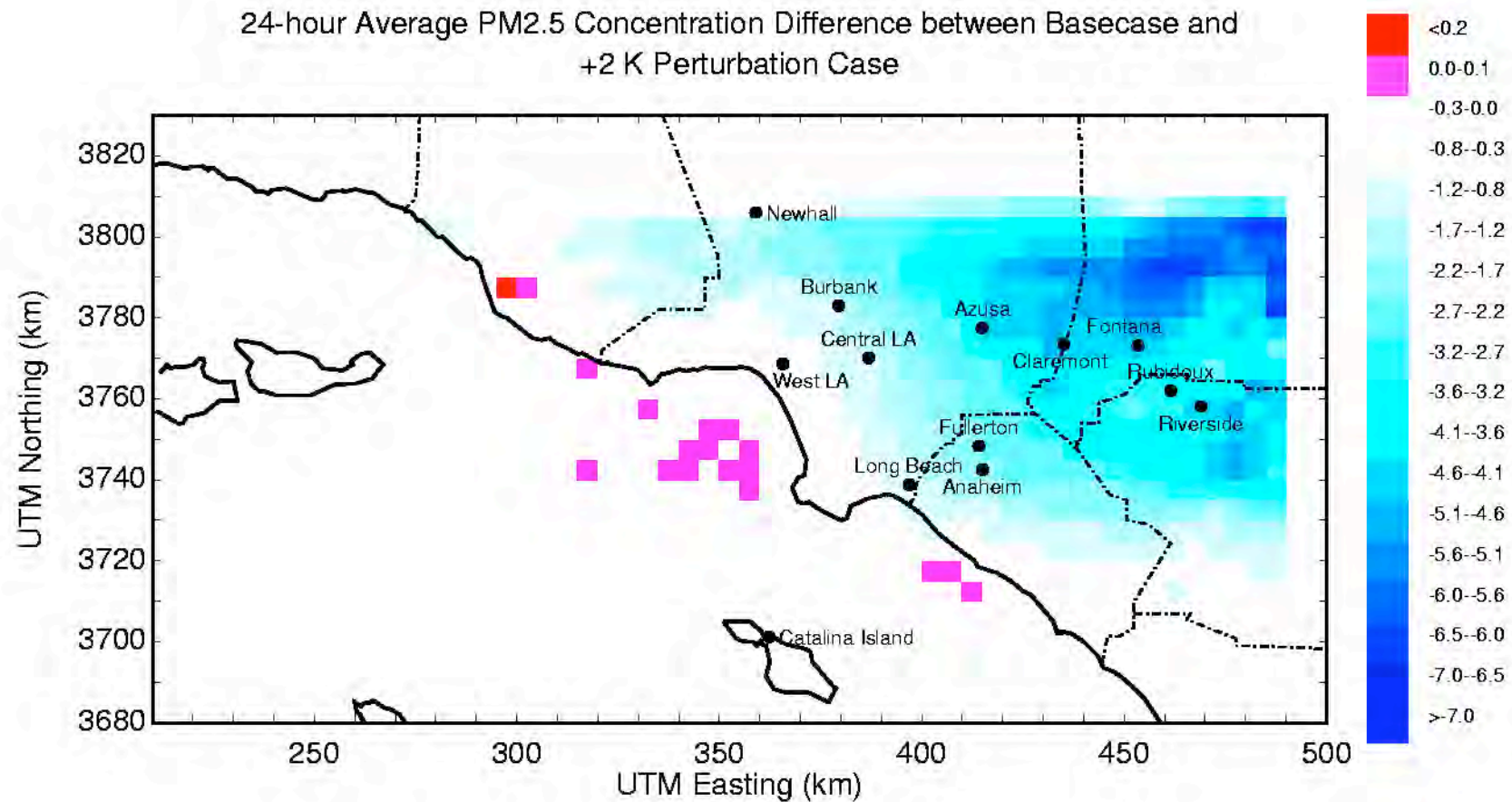
Hourly Average Ozone Mixing Ratio (ppb) Difference between Basecase and +2 K  
Perturbation Case at 1500 PST, September 25, 1996



# Basecase PM2.5 Concentrations



# $\Delta\text{PM}_{2.5}$ Response to +2K



# Emissions Control Plans

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- Emissions control programs must simultaneously achieve Ozone and PM<sub>2.5</sub> control
- Traditional programs focus on NO<sub>x</sub> and VOC control
- Complex non-linear chemistry governs the formation of secondary reaction products
- What is the effect of increased temperature?

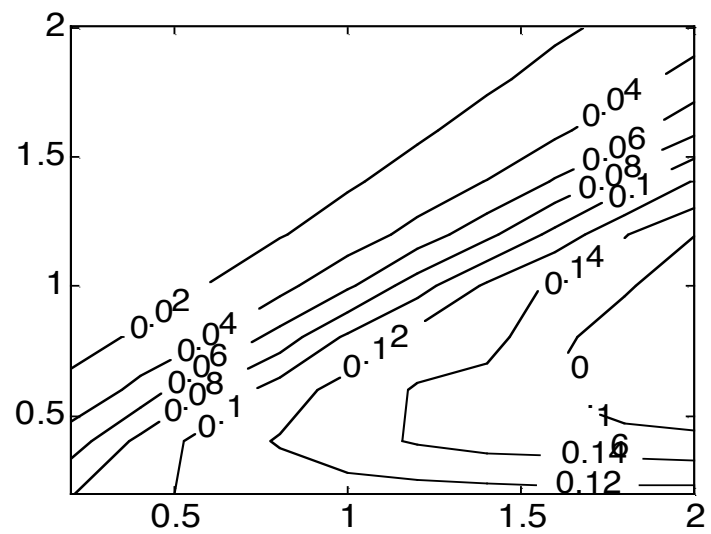


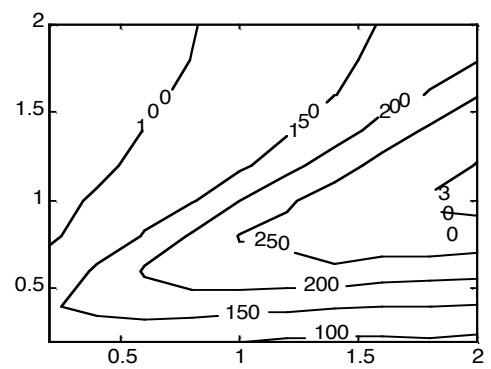


# Increased Emissions at Higher Temperature

	+2K Temperature Perturbation emissions in tons/day			+5K Temperature Perturbation emissions in tons/day		
<b>On-Road Vehicles</b>	TOG	NMOG	NOx	TOG	NMOG	NOx
on-road diesel vehicles	18.82	18.82	156.81	18.82	18.82	155.21
on-road catalytic gasoline vehicles	448.20	393.56	359.16	442.38	388.46	355.50
on-road non-cat gasoline vehicles	157.64	155.58	35.99	155.19	153.16	35.62
other	106.89	106.89	0	121.94	121.94	0
	731.55	674.84	551.96	738.34	682.38	546.33
<b>Other Sources</b>						
seeps/ biogenics	50.63	50.63	0	69.10	69.10	0
Total	782.18	725.47	551.96	807.44	751.48	546.33
Totals for all categories	1766.49	1215.90	919.01	1791.75	1241.90	913.38







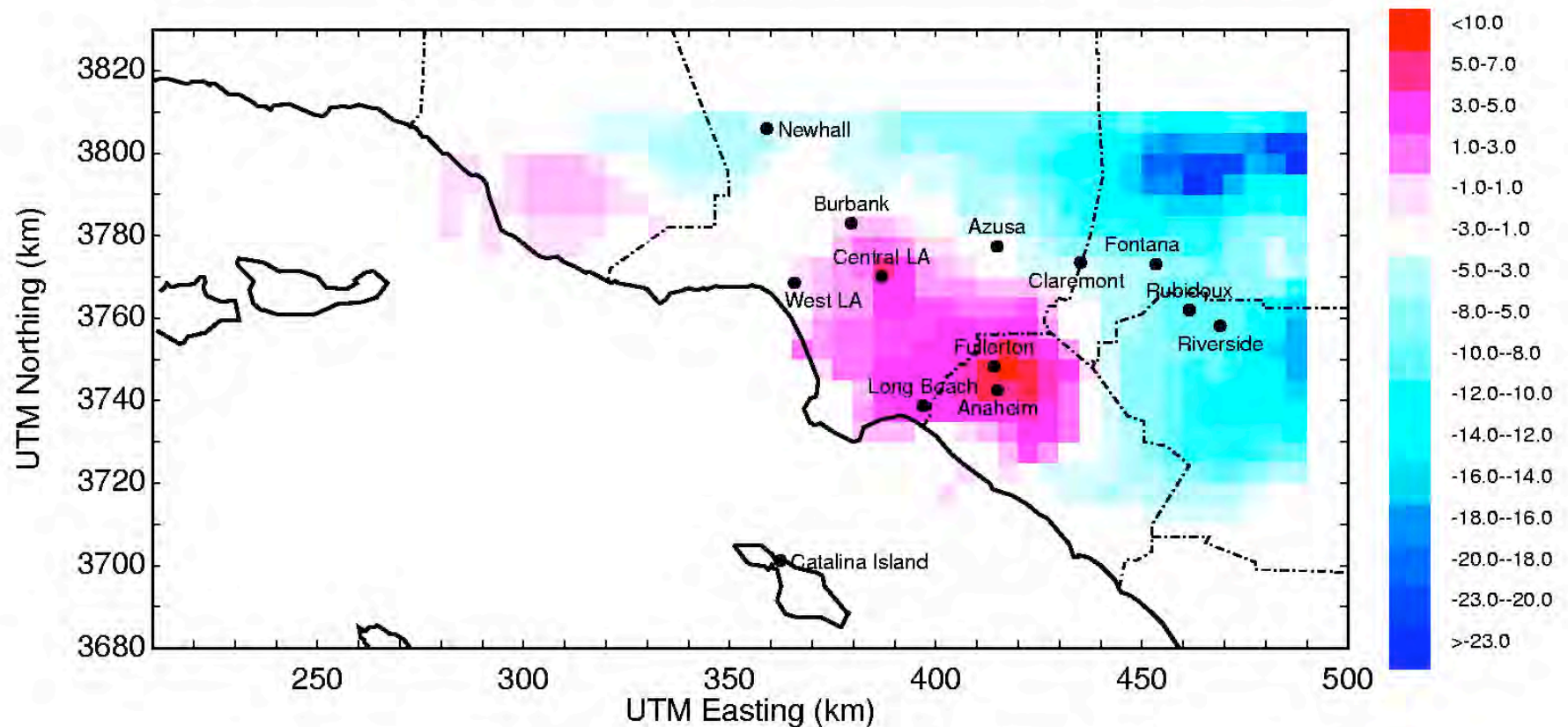
# 1997 AQMP

Control			% Reduction		
Measure #	Control	Measure Description	VOC	NOx	PM10
97cts-02e		further emissions reductions from adhesives - rule 1168	9.6		
97cts-02h		further control of emissions from metal parts and products - rule 1107	29.9		
97cts-02m		further emissions reductions from plastic, rubber and glass coatings - rule 1145	59.1		
97cts-02n		further emissions reductions from solvent degreasers - rule 1122	64.9		
97cts-02o		further emission reductions from usage of solvent - rule 442	39.3		
97cts-07		further emission reductions from architectural coatings - rule 1113	49.5		
97cp-02		emission reductions from consumer products	37.2		
97dpr-01		emission reductions from pesticide application	20.0		
97fug-04		further control of emissions from fugitive sources	8.2		
97cmb-02b		emissions reductions from small boilers and process heaters		80.0	
97cmb-06		emission standards for new commercial and residential water heaters		54.3	
97cmb-09		emission reductions from petroleum fluid catalytic cracking units			41.7
97prc-01		emission reductions from woodworking operations			94.8
97prc-03		emission reductions from restaurant operations	75.0		70.7
97wst-01		emission reductions from livestock waste	29.7		47.2
97wst-04		emission reductions from disposal of materials containing VOCs	30.4		
97bcm-01		Control of emissions from paved roads			29.0
97bcm-03		further emission reductions from unpaved roads			29.0
97bcm-04		Control of emissions from agricultural activities			19.3
97bcm-06		emission reductions from fugitive dust sources			10.0
97adv-prc		long-term control measure for industrial process operations	78.8		
97adv-msc		long-term control measure for misc. VOC sources	75.9		



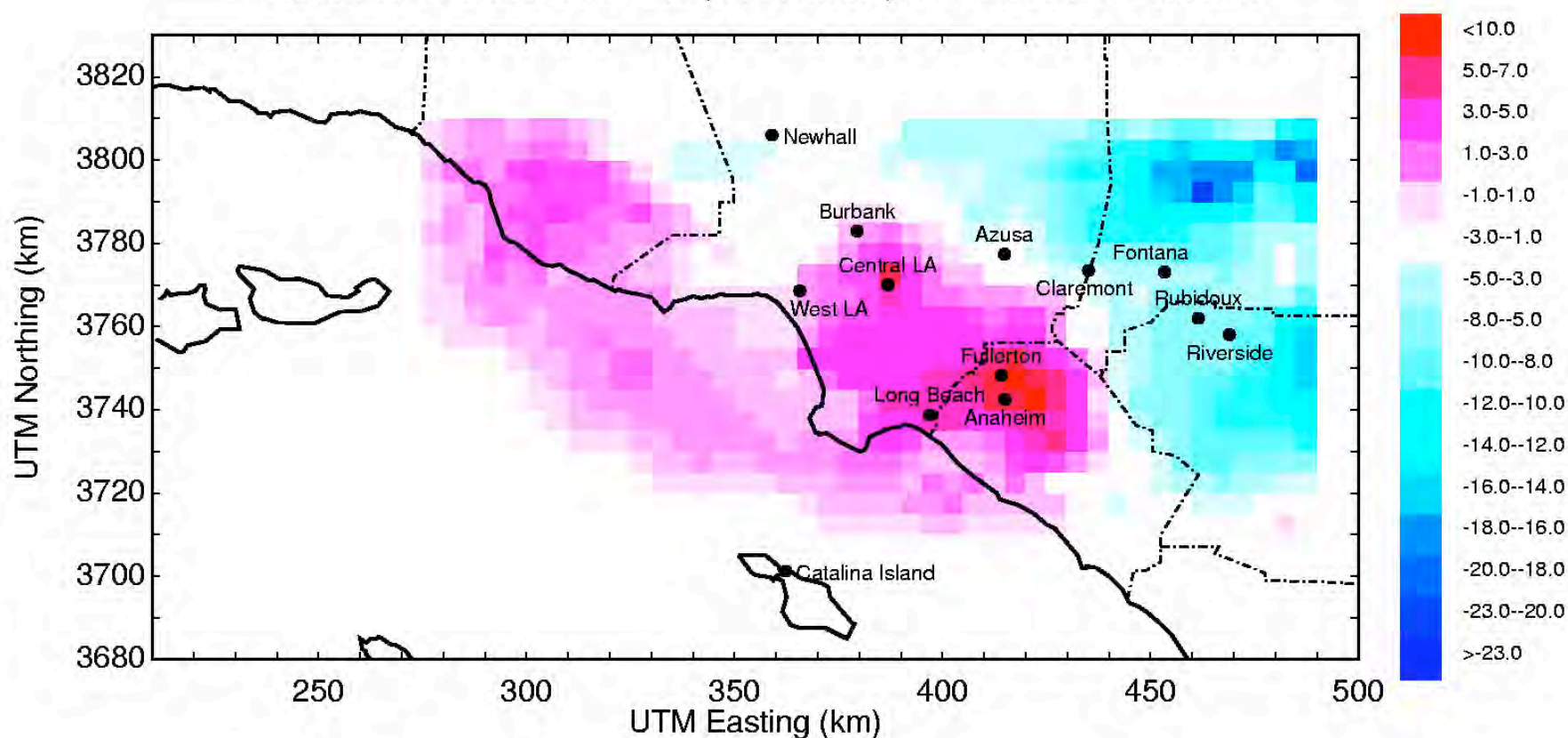
# Basecase O3 Reduction

Ozone (ppb) Difference at 1500 PST, September 25, 1996  
between Basecase with emissions controls and Pre-control Basecase

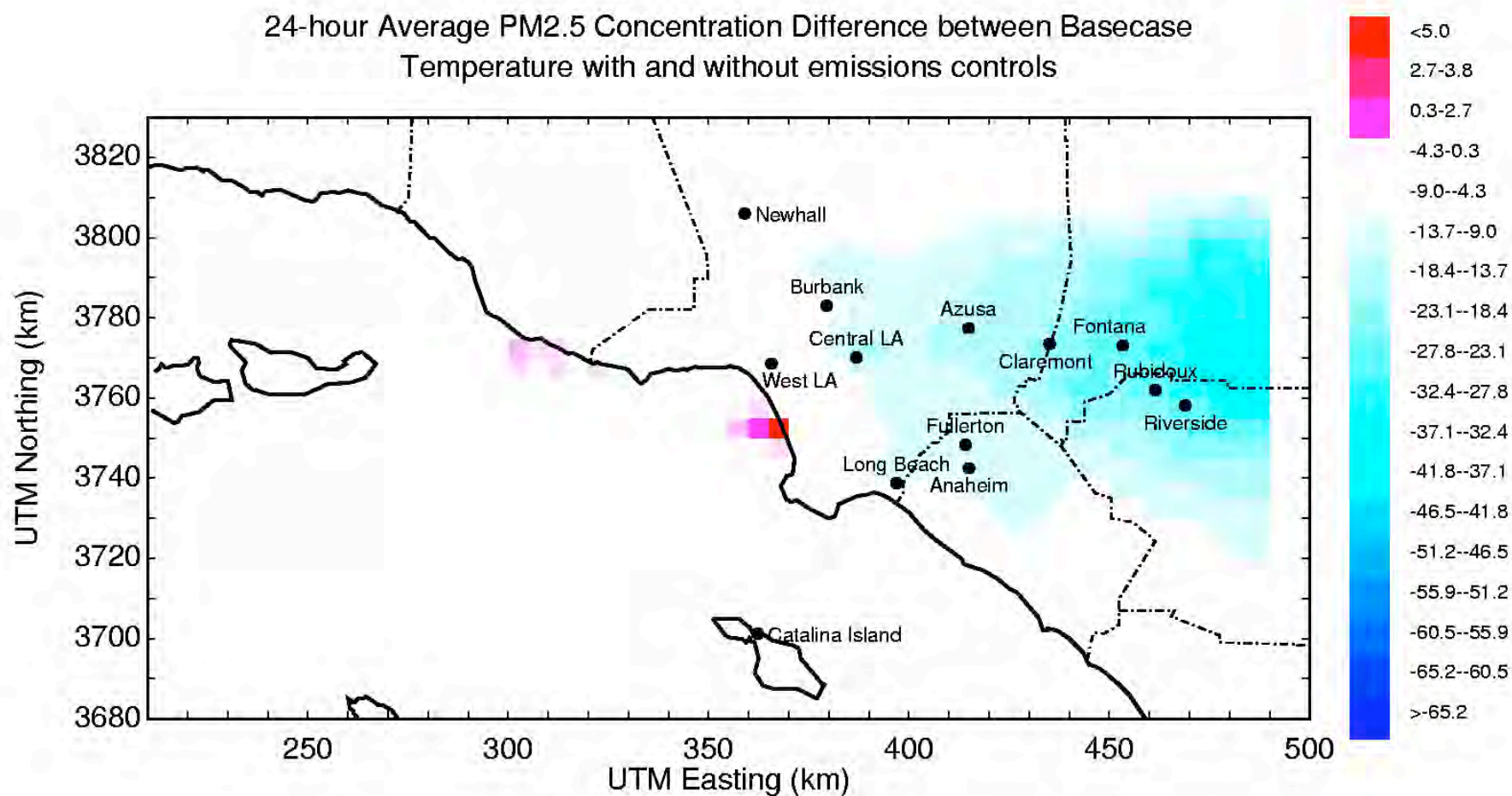


# +2K O3 Reduction

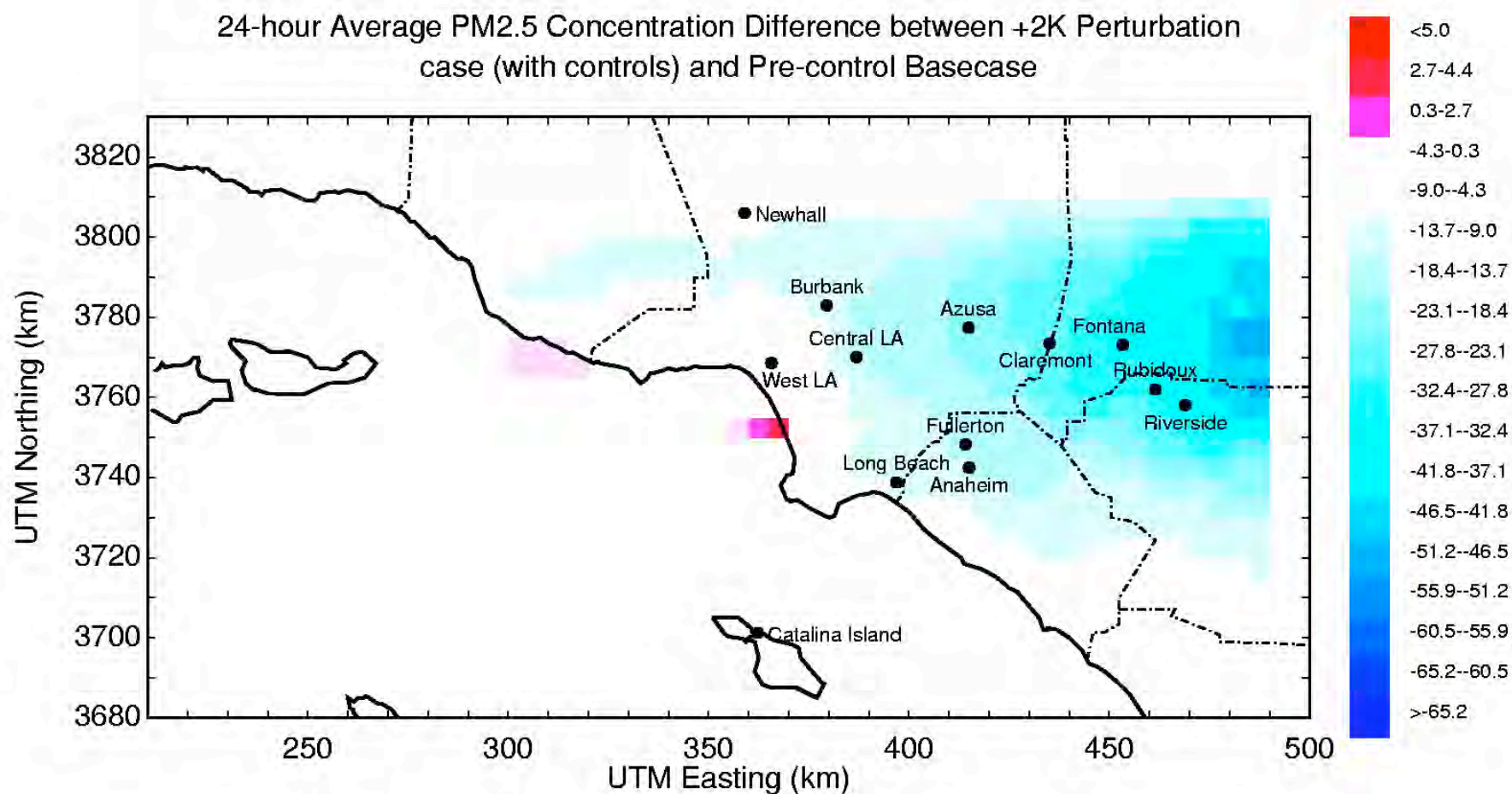
Ozone (ppb) Difference at 1500 PST, September 25, 1996  
between +2K Perturbation Case (with controls) and Pre-control Basecase



# Basecase PM2.5 Reduction



# +2K PM2.5 Reduction





# Preliminary Conclusions

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- Under current conditions in Southern California, elevated temperatures will
  - increase basecase Ozone concentrations
  - Decrease basecase PM<sub>2.5</sub> concentrations due to nitrate evaporation
- The direct effect of temperature on chemical reaction rates outweighs preliminary estimates for effects on emissions rates
- Increased temperature will decrease the effectiveness of Ozone controls and increase the effectiveness of PM<sub>2.5</sub> controls



# Acknowledgements

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California Air Resources Board



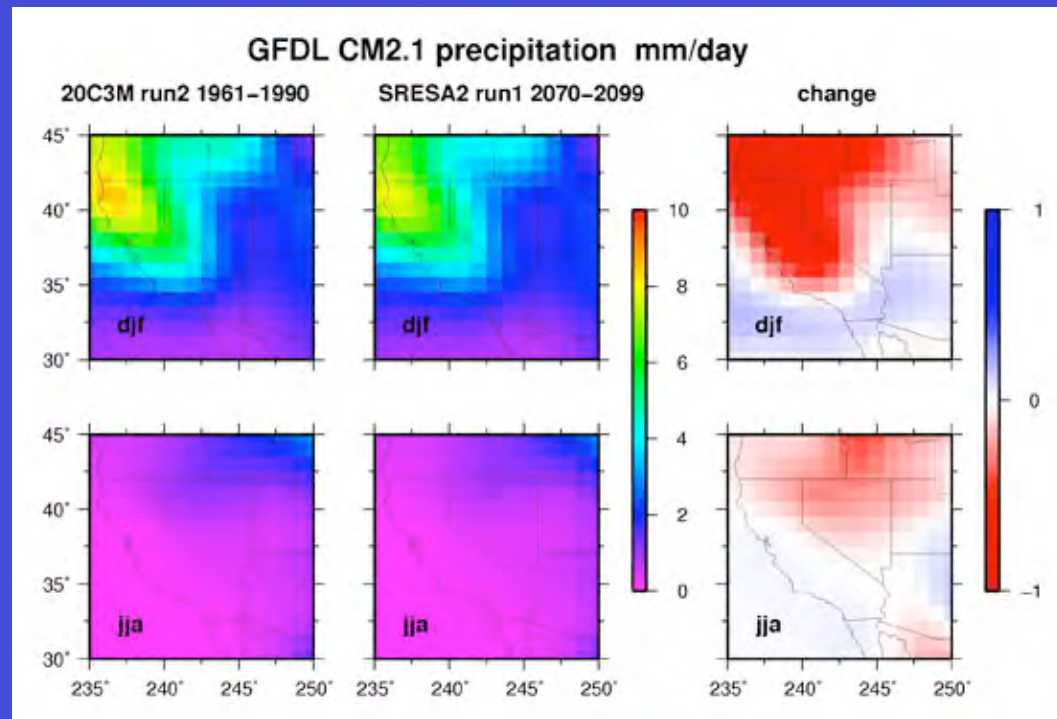


# Climate change projections of air quality over California

## Expectations

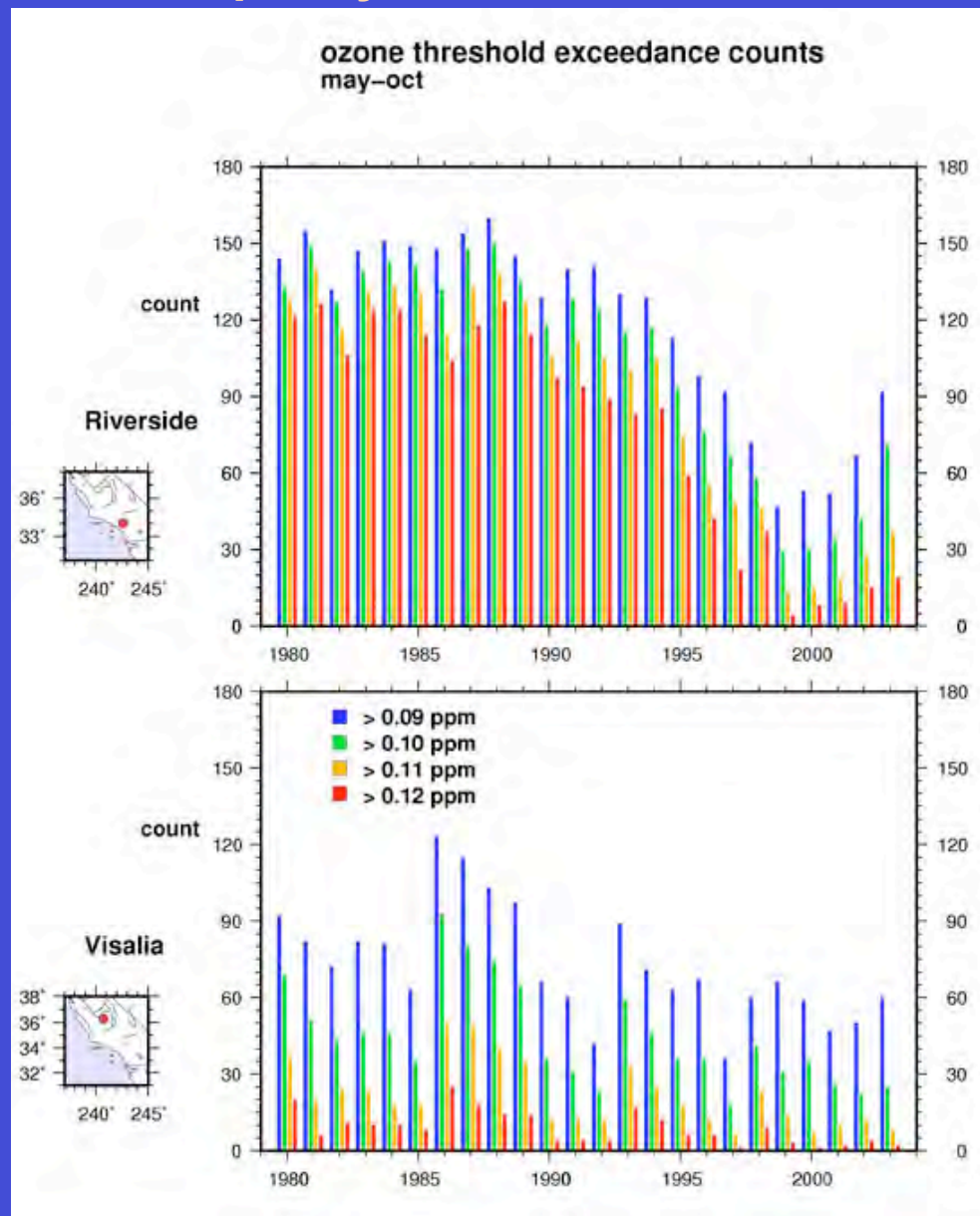
Use like variables from climate model simulations to identify changes in

- number of poor air quality episodes and
- length of poor air quality episodes



# Climate change projections of air quality over California

## Defining the ozone threshold



# Organic Partitioning

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- Semi-volatile organics try to reach equilibrium

$$K_{om,i} = A_{om,i} / G_i M_o \text{ (Odum, 1996)}$$

- $K_{om,i}$  is a function of temperature

$$K_{om,i,T2} = K_{om,i,T1} \times \exp[\Delta H_i / R(1/T_1 - 1/T_2)]$$

- As  $T_2$  increases,  $K_{om,i}$  decreases
  - ▶ more secondary organic in gas phase



# Thermodynamic data for SOA

Gas-phase precursor <sup>a</sup>	Secondary organic	Partitioning coefficient, $K_{om}$ (m <sup>3</sup> /μg)	$\Delta H_v$ (J/mol)	Uncertainty (J/mol)
AAR5	AEA5a	0.093	59112.6	10820.5
	AEA5b	0.01	37593.6	6821.0
AAR6	AEA6a	0.042	64204.7	18029.2
	AEA6b	0.0014	34343.4	2421.3
AAR7	AEA7a	0.093	57503.4	13589.0
	AEA7b	0.01	34671.63 <sup>b</sup>	0.0
APIN	AEAPa	0.171	67743.9	13589.0
	AEAPb	0.004	24674.8	5572.8
BPIN	AEBPa	0.171	62322.8	19032.9
	AEBPb	0.004	24674.8	5572.8
OLE3	AEO3a	0.171	53825.0	3514.3
	AEO3b	0.004	30710.2	10450.7
TOLU	AETLa	0.093	57175.6	11598.9
	AETLb	0.01	33223.2	16936.9



# Case Study: Southern California, September 23-25, 1996

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- Boundary Conditions
  - particle IC/BC based on measurements made at Santa Catalina Island
  - gas-phase IC/BC based on measurements made at more than 30 sites in the South Coast Air Basin
- Initial Conditions / Validation Data
  - PM: measured at 3 sites (Long Beach, Fullerton, Riverside)
  - Gas: measured at +30 sites in the study region



# Case Study: Southern California, September 23-25, 1996

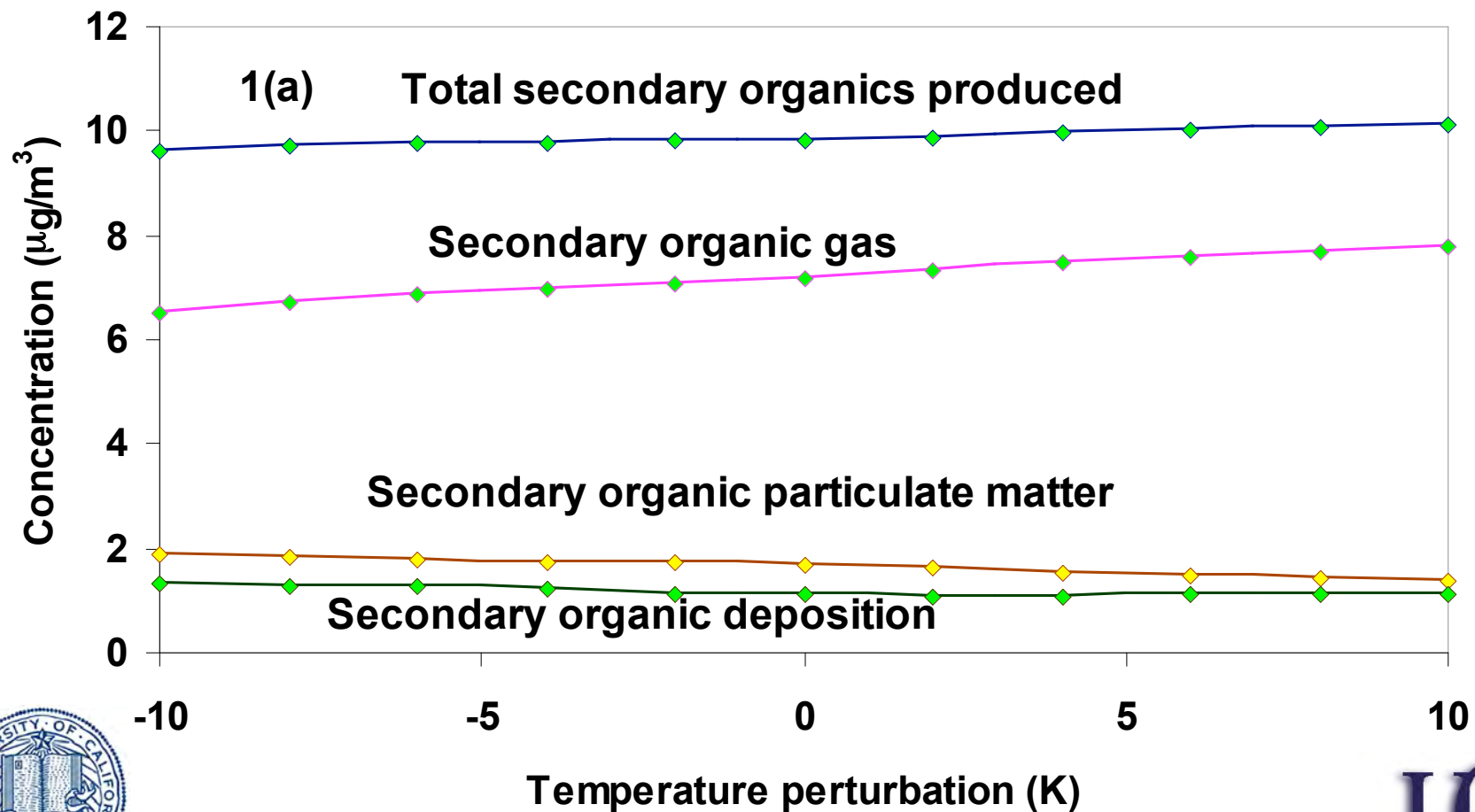
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- Meteorological Data
  - interpolated from observations
- Emissions Inventory
  - mobile sources: day specific
  - area sources: 1995 average day
  - large point sources (RECLAIM): 1997 average day
  - small point sources: 1995 average day
  - ammonia: 1982 inventory updated for 1996
  - biogenic VOCs: 1987 SCAQS inventory

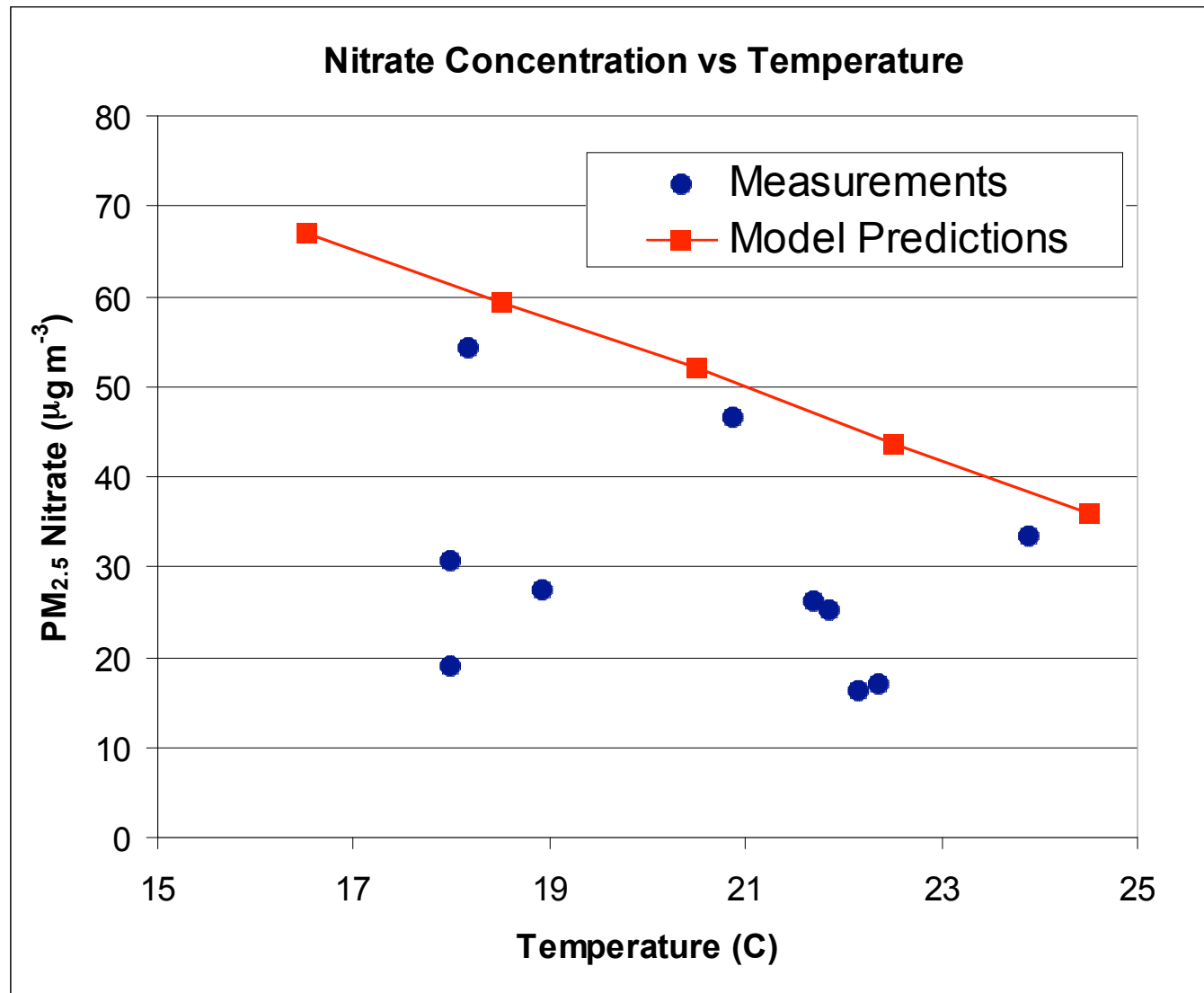




# SOA Response to Temperature



# Comparison To Measurements



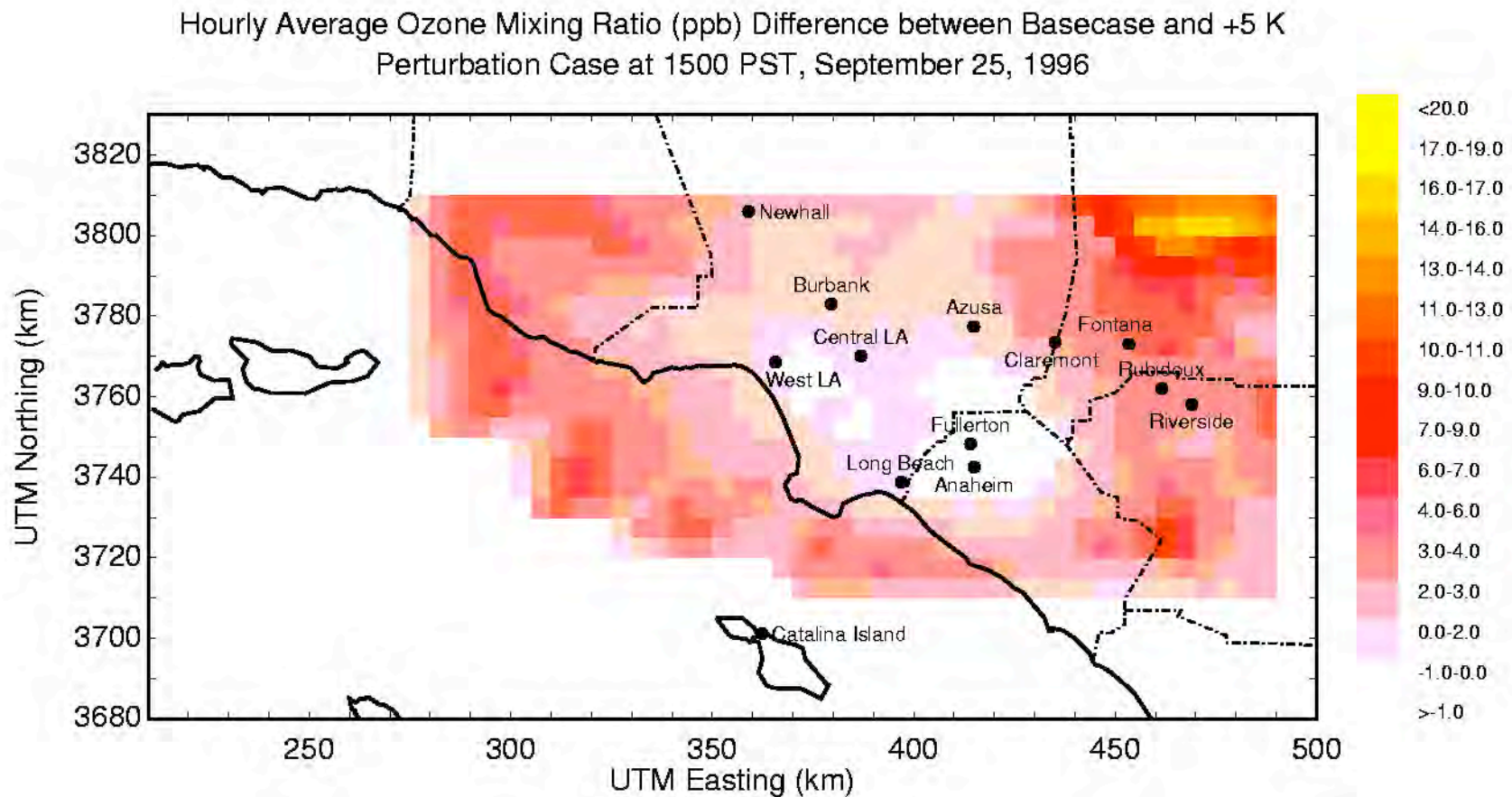
# 3-D Eulerian Model Description

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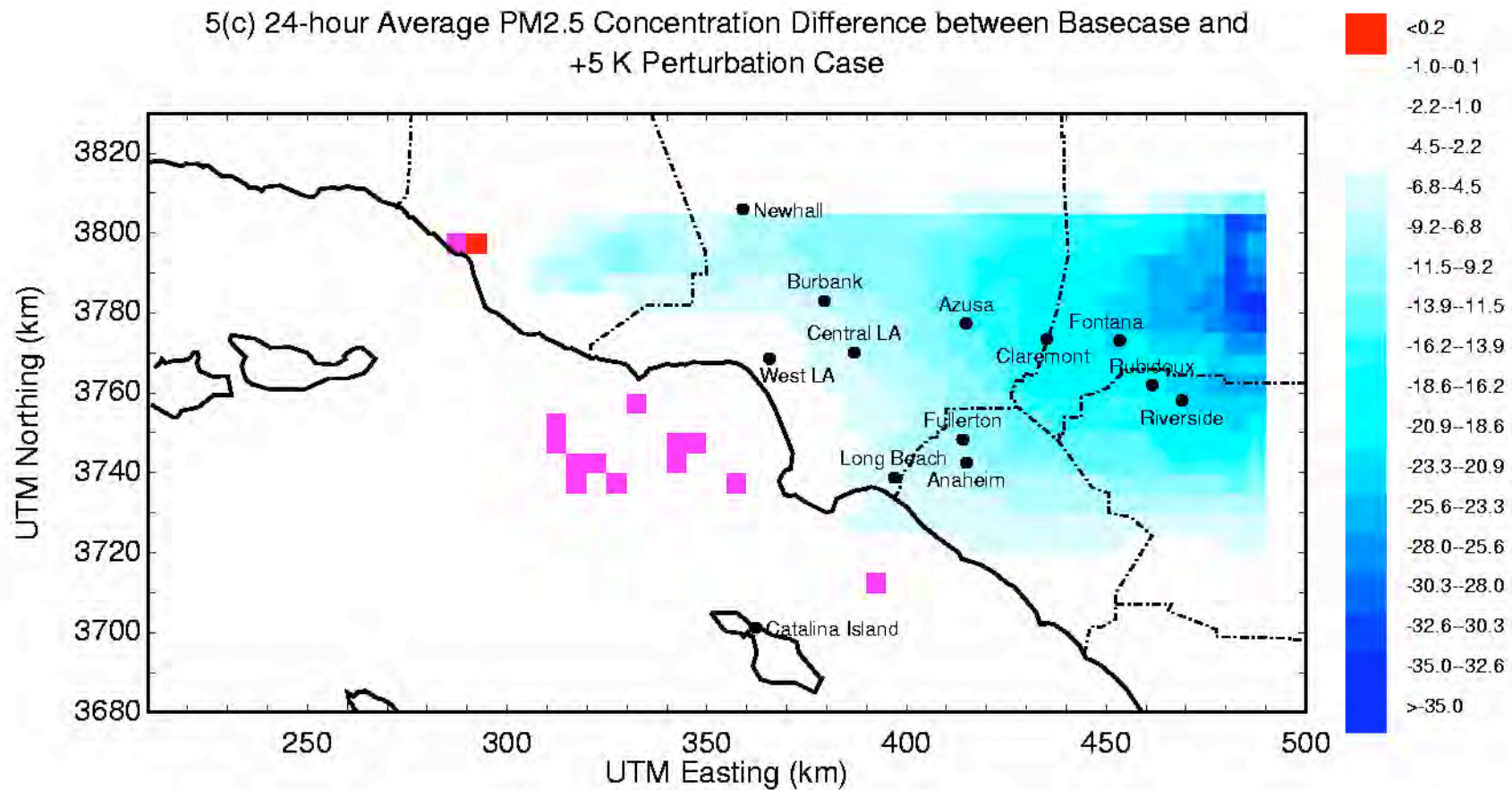
- UCD/CIT Photochemical air quality model
- Particles emitted from different sources tracked separately in 3-D Eulerian framework
- Particles are externally mixed (source oriented)
- Major aerosol processes simulated include emissions, advection, diffusion, deposition, condensation, evaporation and chemical reaction
- Coagulation and nucleation found to be negligible for episode studied



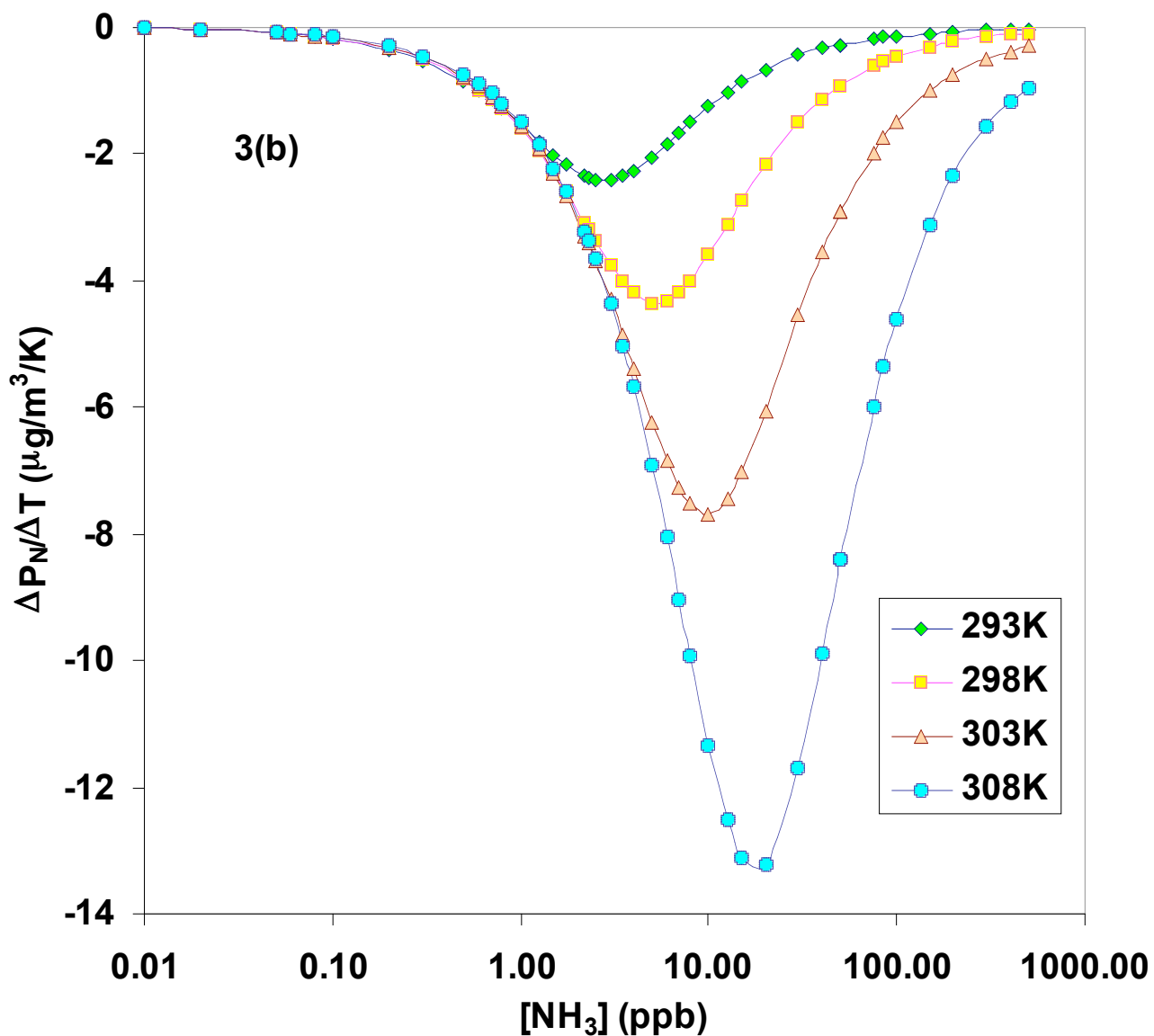
# $\Delta O_3$ Response to +5K



# $\Delta\text{PM}_{2.5}$ Response to +5K

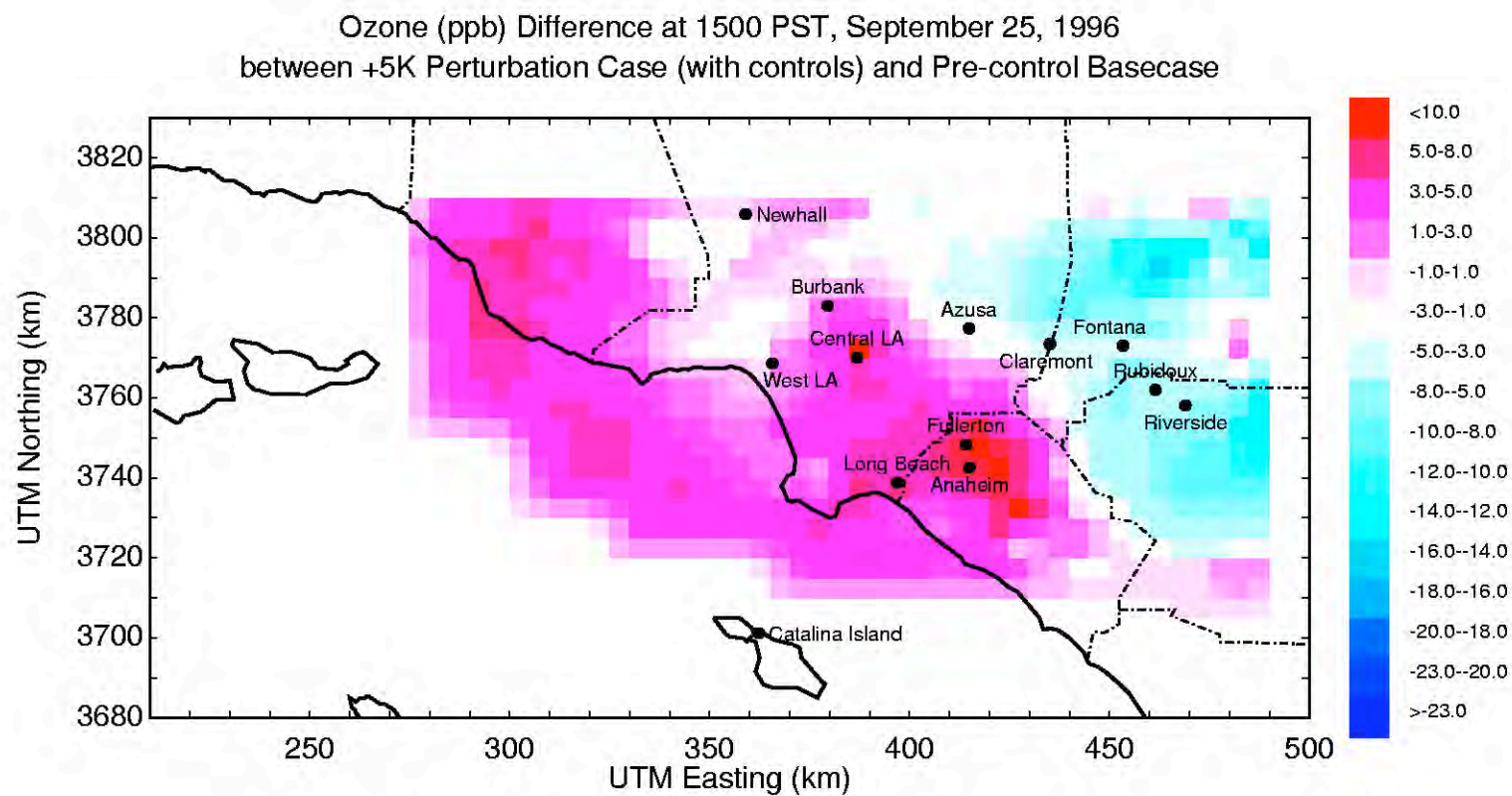


# Nitrate Sensitivity as a Function of NH3





# +5K O<sub>3</sub> Reduction



# +5K PM2.5 Reduction

